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The Extension of the Gas Arc Condition

By H. W. CUMMING, B.Sc., A.R.I.C., *(Member)*

Summary

Following an introductory section in which the derivation of the term "Gas Arc" is indicated, experimental electrical and luminous data on arc discharges through the gases xenon, krypton, argon, neon, and helium, are set out. This investigation has led to the production of a new form of xenon lamp, rated at 1 kw. The possibilities of operating high wattage high brightness sources are discussed, and applications for several types of gas arc discharge lamps are indicated.

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(1) Introduction

The name "Gas Arc" is now associated with a particular electric discharge lamp, first described in a paper by Aldington[1] introducing a newly developed water-cooled lamp which emitted radiation of a sunlight quality from an arc discharge in the rare gas xenon. For some three years following the announcement of this first 5 kw. lamp no other new light source using a rare gas became available commercially, although it was known that research progress was being made[2, 3, 4, 5].

Strictly, the term "Gas Arc" should be applied to a phenomenon or condition rather than to a particular light source. This condition is one of high current density arc discharge through rare or inert gas. To distinguish an arc discharge of this nature by a particular name was considered permissible in view of (i) the associated characteristics—electrical, luminous and otherwise—details of which are set out in the sections below, and (ii) the historic use of similarly distinctive terms for other light sources including the carbon arc and various electric discharge lamps.

For completeness the paper contains experimental data obtained during the development of the 5 kw. lamp; this is followed by a summary of more recent work.

Several types of practical gas arc discharge lamps have now been developed and later sections deal with their characteristics and applications.

The author is with Siemens Electric Lamps and Supplies, Ltd., Preston. The manuscript of this paper was first received on November 14, 1950. The paper was presented at a meeting of the Society held in London on February 13, 1951.

(2) Experimental Data on Rare Gas Discharges

(2.1) General

The data set out in the following sections were obtained from discharge tubes made of fused silica. Electrical connection to the electrodes was provided through hermetic molybdenum foil type seals of suitable current-carrying capacity. When designed for operation on alternating current, the construction was symmetrical with electrodes of thoriated tungsten. For direct current operation the electrode arrangement consisted of a pure tungsten anode and an activated cathode, activation being by alkaline earth material in those lamps where the current did not exceed some 3-4 amperes, and by thoria admixture[6] in other lamps.

In general, lamp design and components were taken freely from existing mercury vapour lamp types; for example, in obtaining the data of Sections (2.6) the practice was to fill a standard 1,000 watt type M.E. lamp (Fig. 1d) with inert gas. Where necessary, however, a special design or construction was developed to enable a desired condition to be attained. Thus, the construction of the orginal water-cooled lamp is unique[1, 7, 8].

The lamps were exhausted on mercury vapour diffusion pump systems. All rare

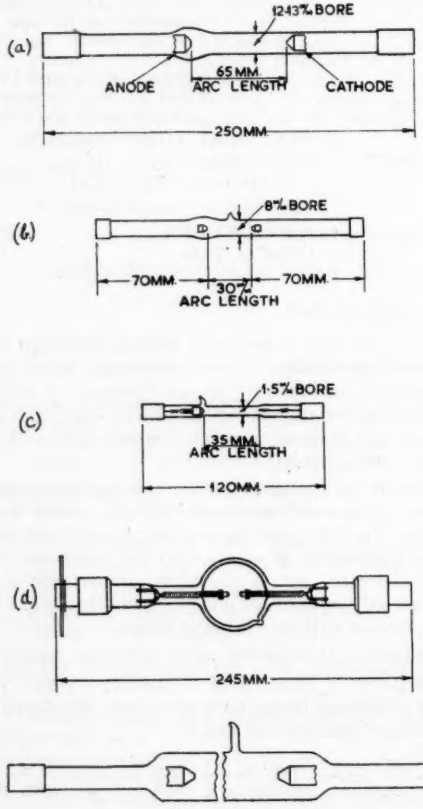

Fig. 1. Construction of various quartz discharge tubes; (a), (b) and (c) designed for water cooling, (d) and (e) for normal air cooling.

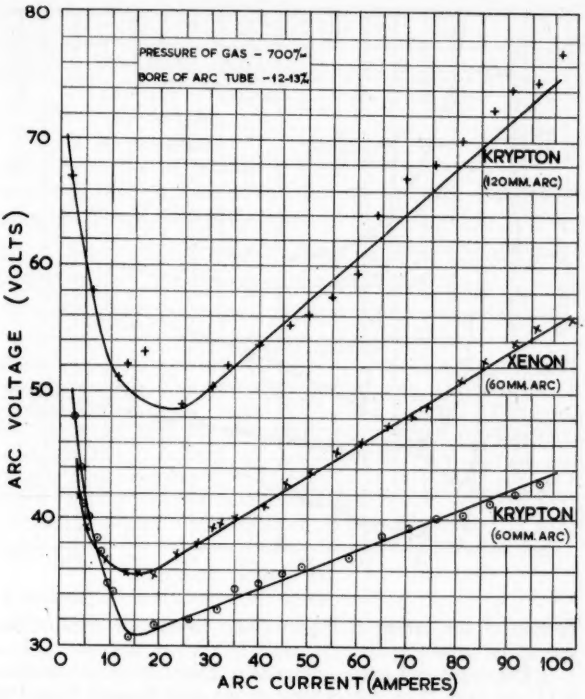

Fig. 2. Voltage/Current characteristics for krypton and xenon.

gases used were of the "spectrally pure" quality and no further purification was attempted; pressures were measured on a mercury manometer at room temperature before "sealing off."

2.2) Voltage-Current Characteristics for Confined Arcs in Xe, Kr, A, Ne and He

With confined arcs it is particularly important to have data on the manner in which arc voltage and wattage change with arc current, the voltage/current characteristics enabling the luminous efficiency data of later sections to be fully utilised.

Once an arc discharge has been initiated in the gas, the current can be varied over a wide range by adjustment of the series ballast (resistive or inductive) while still maintaining a stable arc condition. At pressures up to 2 or 3 atmospheres the arc may be started by the use of a high voltage transformer([1, 7]), by means of special high frequency circuits due to Sparke([9]), by pulse circuits([10]), by electrode probes where the arc is short([11]), or by heated auxiliary electrodes([4, 12]). At considerably higher pressures striking is more difficult, although the circuits developed in conjunction with the restarting of the high pressure mercury discharge are suitable([10, 13]). Striking of these high pressure lamps has also been achieved experimentally by subjecting the lamp initially to liquid air temperatures, thereby reducing the pressure and allowing a simple starting means to be applied([3]).

In general, lamps are more stable on D.C. than on A.C., and for this reason the data of this section were obtained from lamps operating on D.C. Over the central

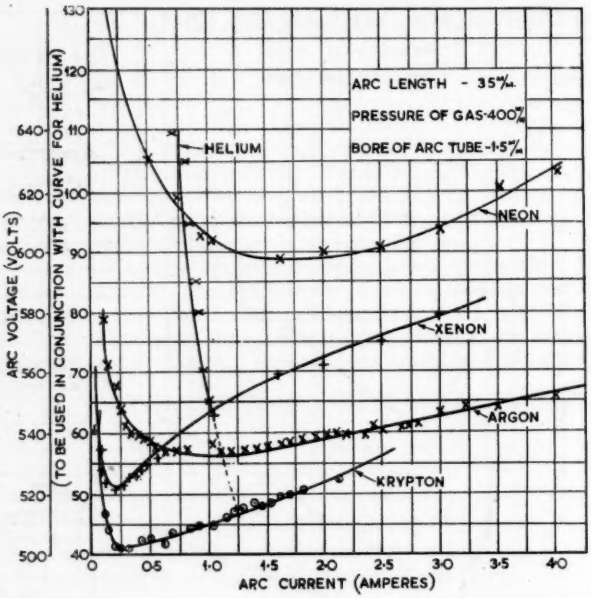

Fig. 3. Voltage/Current characteristics for rare gases.

portion of the curves of Figs. 2 and 3 almost identical results are obtained with lamps operating on A.C.

The original 5 kw. water-cooled xenon lamp was constructed from tubing having a 12 – 13 mm. bore; the general design may be seen from Fig. 1a. As described more fully elsewhere([1], [7]), the construction of this lamp is such that the gaseous contents are confined closely to the arc discharge path since the hermetic seals close the envelope immediately behind the electrodes; this applies also in the designs illustrated at (b) and (c) in Fig. 1. The voltage-current characteristics for this lamp have been described earlier([1], [7]) and are reproduced in Fig. 2; data are also given for water-cooled krypton lamps with arc lengths of 60 and 120 mm. It will be seen that the general shape of the curve is unaffected by arc length and consists of two well defined portions.

A general investigation of the rare gases using the smaller tubes of Fig. 1c gave the volt-ampere curves shown in Fig. 3. The conditions obtained with the larger diameter tubes have been repeated. The characteristic curve for argon follows the same general shape as those for xenon and krypton, although the relative loading at which inflection occurs is higher. The effect is still more pronounced with neon, while with helium it is evident that the point of inflection would only have occurred at conditions outside the scope of the experimental investigation because of limitations imposed by the tube. It is interesting to note that the behaviour of helium offers some practical evidence in support of the theoretical conclusions of Francis([14]) that extremely high loadings would be required with this gas to produce effects similar to those obtained with mercury and other gas fillings at comparatively low loadings.

If E is the D.C. voltage of a given supply and V_L and V_R the voltage drop across a lamp and ballast resistance respectively, then

$$E = V_L + V_R.$$

As the resistance in series with the lamp is reduced the current will increase.

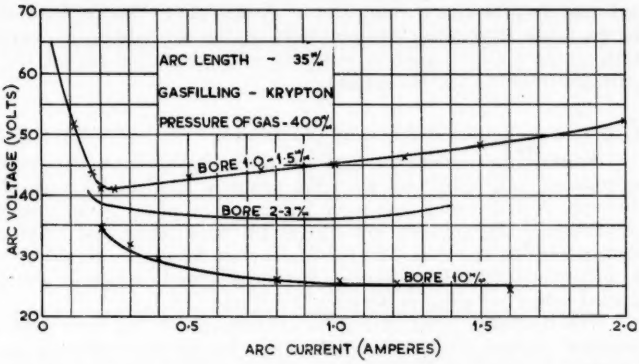

Fig. 4. Effect of proximity of tube walls on Voltage/Current characteristics.

For the 5 kw. xenon lamp the voltage V_L will also increase and, theoretically, it should be possible to eliminate the term V_R, when V_L will equal E. The lamp voltage will then equal the supply voltage, and the series ballast resistance will have been removed. In general practice the tube will not withstand the current and wattage associated with such a condition, but by suitable choice of supply voltage it is possible to operate the 5 kw. lamp without ballast resistance. For example, on a D.C. supply of 65 volts the lamp has an arc voltage of 65 and the current is some 85 amperes.

(2.3) Voltage-Current Characteristics as a Function of Arc Tube Bore

Using the same type of molybdenum seals, anode and cathode as in the tubes of Fig. 1c, a number of lamps of 35 mm. arc length and different tube bores were made containing krypton at 400 mm. pressure. The electrical characteristics are given in Fig. 4. The general shape of the curve is unaffected by the electrodes and seals, although these play an important part in determining the position and orientation of the curve with respect to the reference axes. Increase in tube bore leads to an increase in the current and loading at which the voltage-current inflection occurs. A marked contrast

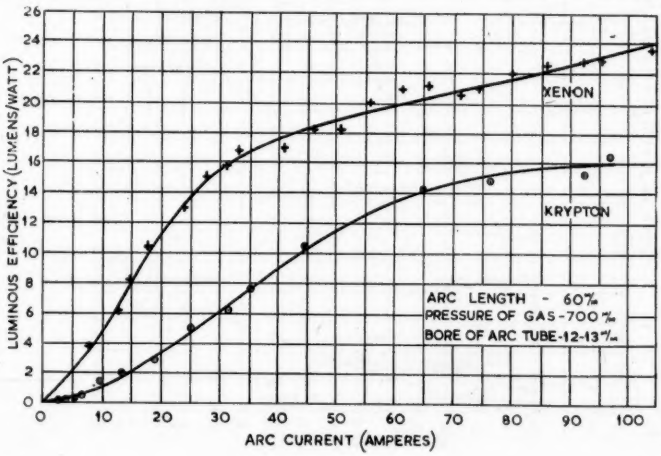

Fig. 5. Luminous efficiency/Current characteristics for krypton and xenon.

is found with the free burning arcs of Section (2.6). The confined arcs of these krypton lamps result from the close proximity of the arc tube walls and from the fact that little or no "free" space is available into which the heated and energised gaseous particles from the arc can expand.

(2.4) Current-Luminous Efficiency Characteristics for Confined Arcs in Xe, Kr, A and Ne

Water-cooled discharge tubes of the type shown in Fig. 1a can be designed to operate at some 25-30 lm/w. when xenon is used at loadings of the order of 100 amperes, corresponding with some 1 kw. per cm. of arc. Fig. 5 exhibits the dependence of luminous efficiency on arc current for both xenon and krypton and is similar to data published elsewhere[1]. Increase in arc length, as would be expected, gives rise to increased luminous efficiency. Results obtained by varying this parameter with air-cooled lamps are given in Sections (2.5.2) and (2.5.3).

The discharge tubes of Fig. 1c containing different gases afford but little data of practical interest on luminous efficiency; for example, varying the current in xenon over the range 1.0 to 3.0 amperes only produced a change in efficiency from 0.42 to 2.0 lm/w. Again changes of small order only are produced with different gases at equivalent loadings. It is assumed that the small cross-sectional area of the arc and the close proximity of the tube walls, maintained at low temperature by the cooling medium, produce severe wall effects resulting in these low luminous efficiencies. Data is given, however, in Fig. 6 for the luminous efficiency of the water-cooled tubes of Fig. 1b containing xenon, krypton, argon and neon; at several points on each curve the corresponding wattage of the arc is indicated.

For equivalent current the luminous efficiencies of the rare gases xenon, krypton,

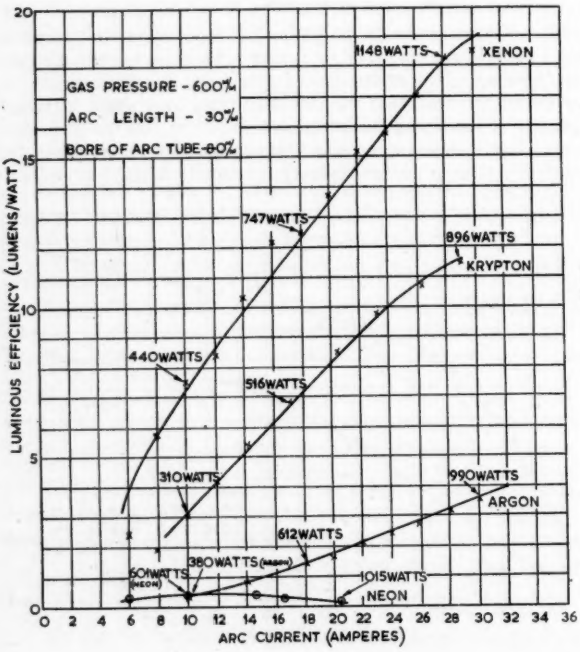

Fig. 6. Luminous efficiency Current characteristics for rare gases.

Table 1.

Data for a Partially Confined Xenon Arc Discharge.

Arc Current (Amps)	Arc Volts	Watts	Lumens
13.6	51	625	7,400
28.8	59	1530	34,500
44.6	68	2740	75,400
52.4	70	3300	95,000
81.2	84	6850	210,000
Arc length : 120 mm. Gas 600 mm. Xenon.			

argon and neon increase in the same order as their atomic weights. When neon is used the luminous efficiency appears to be almost independent of current over the range measured.

(2.5) Characteristics of Partially Confined Arcs in Xenon

(2.5.1.) *General*

Because of the important practical possibilities of the xenon arc discharge with its high luminous efficiency, a separate investigation was undertaken of the properties of arcs in tubular envelopes having an internal diameter somewhat larger than the 12-13 mm. of the lamp in Fig. 1a. A typical construction is depicted in Fig. 1e. The electrodes of thoriated tungsten and the seals were the type employed in the 5 kw. A.C. water-cooled lamp. Table 1 reproduces data from an extensive series of experiments on a lamp having an arc length of 120 mm., an arc tube bore of 25 mm. and containing 600 mm. pressure of xenon. Due to the increased surface area of the discharge envelopes in these lamps, water-cooling was usually unnecessary although operation had sometimes to be limited to periods of short duration.

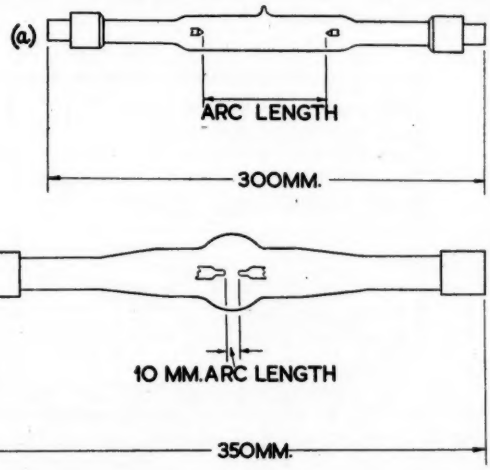

Fig. 7. Construction of air cooled lamps.

(2.5.2) *Voltage-Current Data*

The investigation at moderately low currents (less than 30 amperes) was made with tubes of the type shown in Fig. 7a; this design ultimately formed the basis of a standard light source (Section 3.2). The electrodes consisted of thoriated tungsten, as used in 1 kw. type M.E. lamps, but ground to give a conical tip; their temperature during operation exceeded 1,500 deg. C.

Results given in Table 2 show the voltage-current relationship for a number of arc lengths at a pressure of 700 mm. of xenon. It will be noticed that, unlike the restricted arcs of Figs. 2 and 3, increase of current gives rise to only slightly increased arc voltage; similar results were demonstrated for the water-cooled tubes of larger bore in Fig. 4. Arc voltage increases in the normal way with arc length.

Table 2.

Arc Voltages for Several Partially Confined Xenon Arc Discharges.

Arc current (Amps)	Arc Voltage			
	132mm. Arc	88mm. Arc	41mm. Arc	20mm. Arc
16.5	65.5	44.0	24.20	17.0
19.5	68.0	45.5	24.25	17.0
22.0	70.4	46.5	24.25	17.0
23.0	71.2	47.5	24.30	17.0
25.0	73.0	49.0	24.30	17.0
Gas : 700 mm. Xenon.				

(2.5.3) *Luminous Efficiency-Current-Wattage Relationships*

Luminous efficiency data over the same current ranges for various arc lengths are given in Fig. 8. The wattage loading is indicated at several points on each curve.

In general it will be seen that the luminous efficiency is higher for equivalent currents and arc lengths than that of the tubes described in Section (2.4). The explanation probably lies in the fact that wall and electrode energy losses are reduced in the air-cooled design.

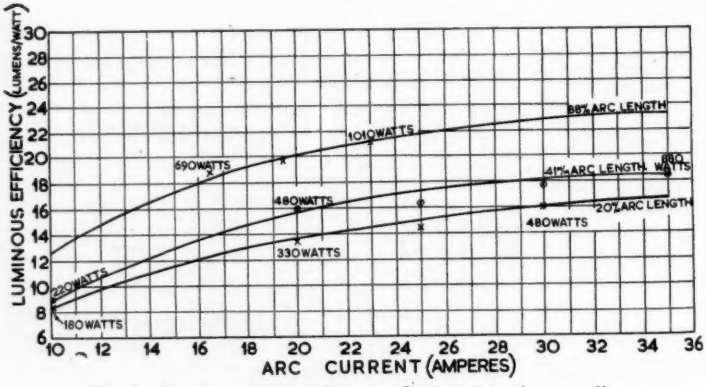

Fig. 8. Luminous efficiency/Current characteristics for partially confined xenon arcs.

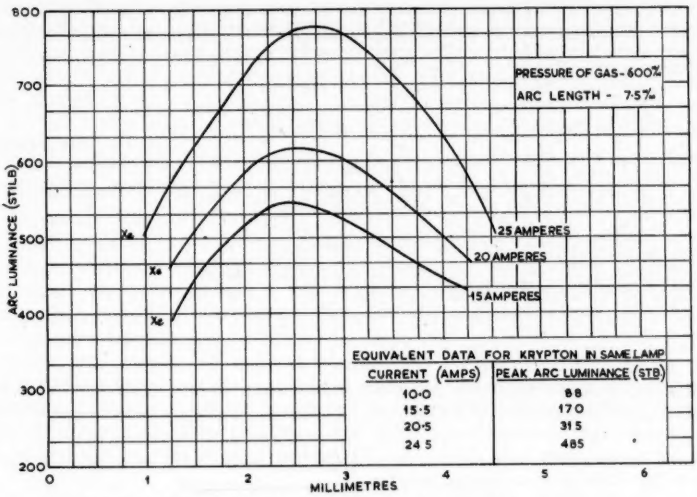

Fig. 9. Centre arc luminance curves for free burning xenon arc.

(2.6) Characteristics of Compact Type Free Burning Arcs

(2.6.1) *Voltage-Current Data*

Using short arc length lamps filled to pressures of 600 and 700 mm., the arc voltage was found to be almost independent of current over the range of current sufficient to raise the electrodes to incandescence. While the greater part of this data was obtained with lamps similar in construction to the 1 kw. ME mercury lamps[15, 16, 17, 18], special lamps of the form shown in Fig. 7b were made for the higher current ranges. In these lamps the electrodes and seals of a 5 kw. A.C. water-cooled lamp were fused directly into a quartz bulb. Results are set out in Table 3 for neon, krypton and xenon with currents up to 25 amperes, and also for xenon over the current range 80-140 amperes.

Table 3.

Arc Voltages for Several Free Burning Arcs.

Current (Amps)	Arc Voltage Xe	Kr	Ne	Current (Amps)	Arc Voltage Xe
10	15	20*	32.5	80	20.6
15	15	17.5	28.0	100	22.3
20	14.5	17	24.5	120	23.3
25	14	17	21.0	140	24.3
Arc length 7.5 mm. Gas Pressure : 600 mm.				Arc length 10.5 mm. Gas Pressure : 700 mm.	

* Unsteady.

(2.6.2) *Arc Luminance-Current Relationship for Krypton and Xenon*

The arc luminance measured at right angles to the electrode axis through a point at the centre of the arc is given in Fig. 9 for both the krypton and xenon lamps of Table 3 at several values of alternating current. The peak arc luminance at the

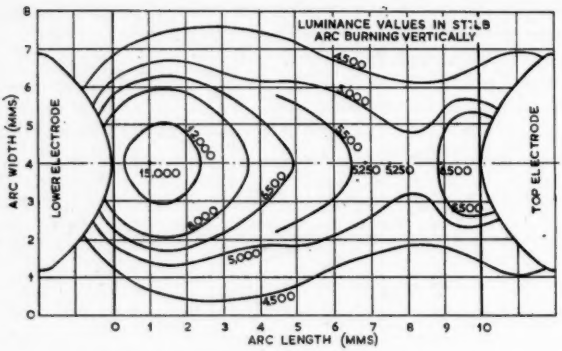

Fig. 10. Typical luminance distribution at 100 amperes for free burning xenon arc.

same position is given in Table 4 for the high current lamp, while Fig. 10 shows the luminance distribution at 100 amperes. The zones of relatively high luminance near each electrode can be clearly seen; they are associated with the cathodic function of each electrode at every half cycle[1, 4]. The upper zone is presumably less bright due to convection effects broadening the arc.

Table 4.

Peak Centre Arc Luminance.

Current (Amps)	Peak Centre Arc Luminance (Stilb)
60	2,900
83	4,500
102	6,150
120	8,400
138	10,200

Arc length 10.5 mm. Gas: 700 mm. xenon.

Table 5.

Spectral Band Luminance Data of Free Burning Xenon Arcs.

Wave band Å	Per cent Luminance			
	15 amps	20 amps	25 amps	Illuminant C
3800–4200	0.028	0.027	0.026	0.026
4200–4400	0.17	0.17	0.16	0.263
4400–4600	0.69	0.65	0.62	0.909
4600–5100	10.5	10.1	10.1	11.103
5100–5600	38.5	37.6	37.3	40.864
5600–6100	36.7	37.9	38.0	36.154
6100–6600	12.2	12.6	12.8	9.954
6600–7600	0.97	0.97	0.97	0.726

Arc length: 7.5 mm. Gas: 600 mm. Xenon.

(2.6.3) *Spectral Band Luminance Data for Kr and Xe*

Little difference was detected visually in the quality of the radiation emitted by free burning and by confined arcs in either xenon or krypton. Spectral band luminance data for xenon and krypton corresponding with the conditions of Fig. 9 are given in Table 5 together with corresponding data for the standard illuminant C; measurements in the eight spectral bands were taken on the instrument developed by Harrison[19].

(2.6.4) *Voltage-Current and Luminance-Current Characteristics as a Function of Gas Pressure*

Irrespective of the pressure developed under normal operating conditions, the pressure of vapour in a practical mercury lamp at room temperature is of the order of 0.0007 mm. and is independent of the weight or quantity of mercury present. With gas fillings, however, high operating pressures (considerably in excess of one atmosphere) can only be obtained by filling the lamp to a pressure which even at room temperatures may amount to several atmospheres The average gaseous density remains sensibly constant in any particular lamp and is independent of temperature. The fact that the sealed envelope, when not in use, may contain gas at high pressure

Table 6.
Effect of Increasing Gas Pressure.

Current (amperes)	0.5 atmos.		1.0 atmos.		1.5 atmos.		2.0 atmos.	
	Volts	Watts	Volts	Watts	Volts	Watts	Volts	Watts
10.5	16	158	16	144	17.6	160	18	160
14	15.5	200	16.3	200	17.2	220	18.4	238
18	15	240	16	260	18	292	19	316
22	15	304	16.5	333	18	362	20.2	400

Arc length : 7.0 mm. Gas : Xenon.

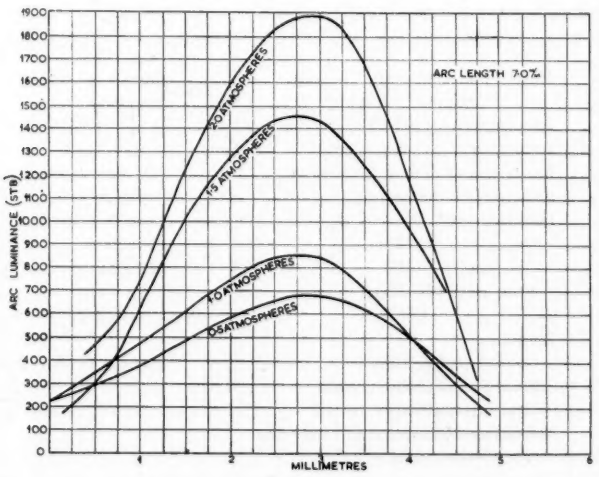

Fig. 11. Centre arc luminance curves for 22 amperes at several pressures of xenon.

is a serious danger and imposes limitations on practical light sources. Extensive measurements of the effect of gas pressure on the voltage-current and luminance-current characteristics of these free burning arcs were consequently restricted to lamps operating at pressures of 0-2 atmospheres, although investigations have been made at considerably higher pressures([3, 11, 20]), and Elenbaas([3]) has reported on the use of pressures up to 20 atmospheres which, under operating conditions, may rise to 300 atmospheres.

The effect of increasing the gas pressure is shown in Table 6 and Fig. 11. It will be seen that for equivalent currents (i) a higher loading may be obtained in the arc, and (ii) the luminance associated with pressures of the order of two atmospheres is related to that at one atmosphere by a function of the form

$$B_2 = k.B_1$$

where B_2 and B_1 are the peak arc luminance values for initial (room temperature) gas pressures of two and one atmospheres respectively, and k is a constant of numerical value greater than unity. k was found to vary with different orders of current and with particular electrode and envelope configurations; values of the order of 2.5 and 3.0 were encountered.

The luminous efficiency of the smaller 1-kw. lamp of Section (2.6.2) is low, even when xenon is used. At two atmospheres pressure the luminous efficiency would increase, but at low currents would still not approach the 30 lm./w. achieved with other constructions. The data of Schultz ([11]), therefore, are of particular interest, as he has reported luminous efficiencies of the order of 35 lm./w. at currents of about 8 amperes for short (4 mm.) free-burning arcs in 37 atmospheres pressure of xenon.

(3) Practical Light Sources

A number of practical light sources have resulted from the work described above; two have been standardised and are available commercially.

Table 7.

Characteristics of 5 kw. type XA/U Lamp.

	A.C.	D.C.
Type	XA/U	XA/U
Rating : Lamp watts	5000	5000
Supply voltage	200/250	100/250
Arc voltage (approx.)	65	65
Arc current (approx.) (amps.) ...	85	85
Luminous efficiency (lm./w) ...	25–30	25–30
Average life (hours)	100	100
Dimensions :—		
Overall length (mm.)	250±3	260±3
Arc. length (mm.)	65±1	65±1
Max. external diam. (mm.) ...	22	22
Caps	Brass Cylinders	Brass Cylinders
Jacket :—		
Overall length (mm.)	250±1	250±1
Max. external diam. (mm.) ...	40	40
Min. internal diam. (mm.) ...	26	26
Recommended minimum water flow rate (litres/minute)	5	5

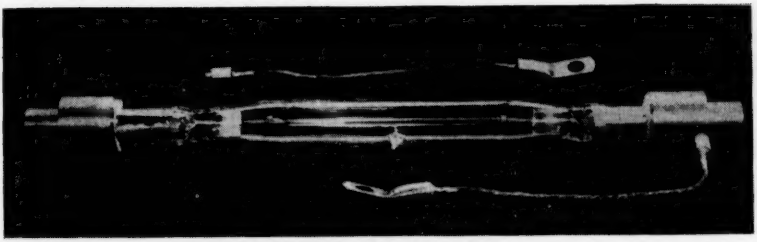

Fig. 12. Photograph of 1 kw type XB/U lamp.

(3.1) 5,000-watt XA/U Lamp

The 5,000-watt forced liquid cooled lamp (type XA/U) has already been described in detail (1.7). The lamp may be operated at any loading from 1 to 5 kw. to produce a total luminous output of 12 x 10^3 to 150 x 10^3 lumens; the radiation has spectral qualities similar to those of a total radiator of colour temperature 5,500 deg. K. The principal characteristics are summarised in Table 7.

(3.2) 1,000-watt XB/U Lamp

The recently standardised 1,000-watt normal air-cooled lamp (type XB/U) is based on the design illustrated in Fig. 7a. A photograph of the commercially available lamp showing caps and flexible lead connections is reproduced in Fig. 12.

Although a high luminous efficiency was a primary objective in the design of this lamp, other factors influenced its final construction. Increased arc length (i) tends to promote arc movement or flicker, (ii) may produce an arc voltage of such magnitude or wave-form as to be electrically unstable on normal mains voltage, (iii) may prevent horizontal operation due to aggravating the phenomenon of arc bowing, and (iv) causes an increase in the voltage required to initiate the arc. On the other hand, the higher the arc voltage, the lower the current for a given wattage, resulting in (i) less electrode sputter, and (ii) reduced heating, and therefore reduced oxidation, of seal extremities. Certain values of arc voltage and current may enable a new lamp to be operated from standard choke gear already available. Choice of arc tube diameter influences (i) the temperature of operation of the envelope and therefore the rate of

Table 8.

Characteristics of 1 kw. type XB/U Lamp.

Type	XB/U
Rating. Lamp watts	1000
Supply voltage	200/250 A.C.
Arc voltage (approx.)	45
Arc current (approx.) (amps.)	22–25
Luminous efficiency (ml/W)	22–25
Average life (Hours)	500
Dimensions :— ...	
Overall length (mm.)	300±5
Arc length (mm.)	85±2.5
Maximum external diam. (mm.)... ...	ca 30.
Cap	Brass cylinders Flexible leads

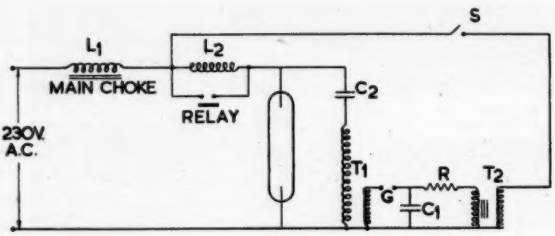

Fig. 13. Diagram of circuit for starting and operating 5 kw XA/U and 1 kw XB/U lamps.

chemical change in the material of which the lamp is made, (ii) the constriction or otherwise of the arc, and (iii) the optical stability of the arc. The life of the lamp, influenced to different degrees by certain of these factors, has to be sufficient for its intended uses and applications.

The main characteristics and dimensions of the lamp are given in Table 8. The radiation is of similar quality to that of the 5-kw. source, and light output may be adjusted by controlling the loading. For operation in the horizontal position a magnetic arc deflector is employed to prevent overheating of the envelope due to impingement of the arc stream; sufficient control can be exercised by utilising the magnetic field associated with the current flow in a conductor placed above the lamp and attached to one end cap[21]. In the vertical position either cap may be uppermost.

An inherent feature of any gas arc lamp is that full light output is obtained immediately the arc discharge forms; there is no "run-up" period. Again, due to the gaseous density remaining constant, the voltage required to "restrike" the arc at various periods after the lamp is switched out undergoes no appreciable change. A further effect of there being no "run-up" period, and therefore no condition in which the arc current exceeds that of the normal operating state, is that the number of switchings influence the life of these lamps less than they do the lives of other sources such as the mercury MD lamps.

While extensive data have not yet been compiled, the life of the 1,000-watt lamp appears to exceed 500 hours.

The striking voltage of the lamp is of the order of 4 kv. For starting, a high voltage transformer may be used having an open circuit voltage of 4 kv. and a short circuit current of some 0.5-1.0 ampere[1, 7]. A preferred method, however, is to provide the high voltage from a Tesla coil device at a frequency of the order of 0.1 m/cycle/sec. This produces ionisation and ultimately causes the arc discharge to form[9]. A well designed circuit consumes less than 100 watts from the mains for the fraction of a second in which it is used. Fig. 13 gives details of the electrical components. The method of operation is as follows: On closing the "push-button" switch S, the transformer T_2 charges capacitor C_1, through the resistance R, to a voltage of about 900 volts which breaks down spark gap G. High-frequency oscillations are produced in the primary and secondary windings of coil T_1 and, because of the impedance of the air cored inductance L_2 (0.1 henrys), these oscillations appear across the lamp terminals; sufficient turns are put in the secondary winding of T_1 to give a voltage which will ionise the lamp. The main arc forms and inductance L_2 is automatically short-circuited by a relay operated by the voltage developed across choke L_1. Arc current is controlled by choke L_1. Switch S may be opened.

(3.3) High Brightness Sources

Sources of high intrinsic brightness appear to be limited to the compact source type of xenon arc. Developments have largely been concerned with lamps of high current (of the order of 100 amperes), preferably containing gas at two atmospheres

pressure; higher pressures have been excluded because of practical safety considerations. Lamps of lower current consumption have been investigated but, unless effective means can be found to allow high gas pressures to be used with safety, it would appear that the use of such lamps will be limited to highly specialised applications.

A typical construction suitable for high current is the A.C. lamp of some 2 kw. rating illustrated in Fig. 7b. The characteristics for both continuous operation and pulse conditions of loading (Section 4) are given in Table 9. Standardisation of the lamp waits on development of a final design.

Table 9.

Characteristics of 2 kw. Lamp.

	Continuous Rating	Flashing at 100 amperes
Current (amperes)	80	100
Arc voltage	ca. 21	ca. 23
Approx. peak arc luminance (stilb)...	8000	15000
Centre arc luminance (stilb) ...	4400	6100
Bulb diameter (mm.)	50	50
Approx. overall length (mm.) ...	350	350
Arc length (mm.)	10.0	10.0
Gas: 700 mm. Xenon.		

The compact type xenon arc gives radiation of a quality similar to that from the 5 kw. XA/U and 1 kw. XB/U lamps. Light output may be obtained instantly and the lamp may be switched in or out under all conditions of operation. A diagram showing brightness distribution for a one atmosphere lamp at 100 amperes has been given in Fig. 10; values of brightness corresponding to an arc current of 80 amperes may be obtained, to a first approximation, by multiplying by a factor of 0.75. At 100 amperes a two atmosphere lamp gives a somewhat different brightness distribution. The centre arc brightness is approximately 2.5 times that shown in Fig. 10 for the one atmosphere lamp, while the brightness of the zones near the electrodes increases by a greater factor.

The dissipation of 2 kw. in this lamp is achieved by the use of a current of some 100 amperes compared with 40 amperes for a typical 2½ kw. mercury lamp[22]. This is an inherent disadvantage resulting from the low arc voltage of the compact type xenon arc discharge. It follows that in operation on, say, 230v. single phase A.C., the overall wattage taken from the mains is 100 x 230, i.e. 23 kw., assuming resistive ballast; with purely inductive ballast the power factor will be less than 0.1. No solution

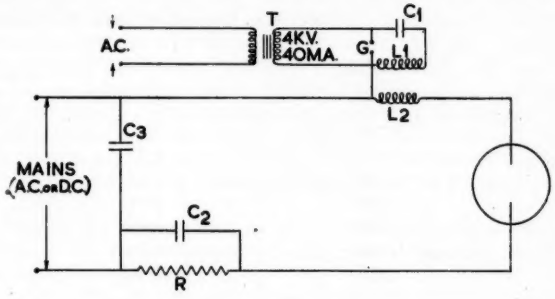

Fig. 14. Diagram of special starting and operating circuit for compact type free burning arc lamp.

to this inefficiency with direct current lamps appears possible, except where special generators are available or several lamps can be operated in series. If the lamps are operated on alternating current, step-down transformers and capacitor power factor correction can be used.

Where the applied voltages are less than some 200v. A.C. or 100v. D.C. the circuit of Fig. 14 can be used for starting and operating the lamp, although the methods already referred to are sometimes applicable[1, 7, 9]. The transformer T, energised from alternating current mains, charges the capacitor C_1 to a voltage which breaks down the spark gap G. A normal resonance effect follows and a high voltage at a frequency of some 2 m/cycles per second is induced in coil L_2. The discharge path is ionised and the arc forms. If R is an inductive ballast it is advisable to employ a capacitor C_2 across its terminals. Similarly the mains supply, whether A.C. or D.C., should be protected from H.F. currents by a capacitor C_3; both C_2 and C_3 may be of the order of 0.5 μ F. L_1 and L_2 consist of some half dozen turns of stout copper strip located close to each other.

(4) Applications

Applications for the standard 5 kw. and 1 kw. lamps depend primarily on the excellent colour and accurate colour rendering properties of their radiation. The ability of these lamps to give full light output instantaneously is also important for some applications.

Uses of the 5 kw. lamp include (i) illumination of photographic studios for colour transparency processes, and (ii) colour matching and comparison where high levels of illumination are required[1,7]. Special applications are based on the spectral composition of the radiation in the ultra violet and near infra red regions. Although the smaller water-cooled tubes of Fig. 1b have been used as an alternative to the hydrogen lamp[23] as a source of continuous U.V.[24] it is not certain that the U.V. output from rare gas arc discharge lamps operating at low currents exceeds that of the hydrogen lamps. The 5 kw. lamp with quartz flow jacket, however, has a greater energy output at any wavelength in the U.V. than commercially available hydrogen tubes. The near I.R. output of the 5 kw. standard lamp has been compared with that from a 5 kw. tungsten filament lamp. Measurements have been taken (i) with a ceasium photocell, whose spectral sensitivity was reduced to that of the I.R. film by a filter combination comprising 6 mm. thickness of Chance Bros. type O.N. 20 glass plus an Ilford 207 I.R. filter, and (ii) by direct photographic comparison. For periods of time of the order of five seconds the xenon lamp can be overloaded to some 13 kw., when the I.R. output is found to be about four times that of the incandescent source.

Table 10.

Near I.R. Output of Type XA/U Lamp.

Current (amperes)	Arc Wattage (kw.)	I.R. Output Expressed as percentage of that of 5kw. Filament Lamp
50	2.65	61.5
70	4.27	108
85	5.53	150
100	6.85	204
120	8.90	271
140	11.28	350
150	12.60	370

Table 10 contains experimental data[25] whose importance in certain branches of I.R. photography will be apparent.

The 1 kw. lamp is suitable for any of the colour applications where the larger 5 kw. source has been used, although the illumination will be less. Additional advantages result from the longer life of this lamp and from the fact that water-cooling is not required. The light source, once ignited, requires no further attention and will give either constant or modulable light output over a period in excess of 500 hours.

This 1 kw. gas arc lamp has been used for the fading of fabrics, textiles and papers, replacing the 1 kw. carbon arc. Advantages of the gas arc lamp for this application include: (i) Total enclosure with consequent freedom from the troublesome humidity disturbances which, in certain apparatus, involve the provision of an open water tray and vapour circulating fan; (ii) Cleanliness; (iii) Operation from A.C. supply, and (iv) Trouble-free operation for long periods with much reduced maintenance.

Another application is associated with rocket and jet developments. A number of these light sources, burning horizontally in parabolic trough reflectors, illuminate the base of experimental operation pits, making possible both visual and photographic observation of phenomena in the pits.

Investigations are being made to determine the effects of xenon radiation on the growth of grass and clover plants. If successful this lamp may replace natural sunlight for experimental studies of plant growth under continuous and high illumination[26].

The high brightness compact source lamp is intended primarily as a projection lamp for colour film and colour slides. Here, the absence of "run-up" and the ability of the lamp to give maximum light output instantaneously may be important advantages over mercury or mercury/cadmium sources.

The instantaneous production of full luminous flux has resulted in the adoption of the xenon arc discharge in a recently developed signalling lamp. The construction is based on the 2 kw. source and involves the incorporation of a third or auxiliary limb in the quartz bulb; the third electrode is in the form of a short stout filament which can be brought to incandescence. This auxiliary electrode enables (i) rapid "striking" or "restriking" of an arc under all conditions of temperature in a pressure of one or two atmospheres of xenon[4, 12] using normal mains voltages only, and (ii) the continuous provision, during operation, of an auxiliary arc between the auxiliary and lower main electrodes, providing sufficient ionisation to bring in the main arc on the movement of a Morse key and contactor arrangement. Signalling of Morse characters at speeds up to some 20 words per minute is possible with this lamp.

(5) Conclusion

The investigation of the high current density arc discharge in gases, of which krypton and xenon are the most important, with a view to developing new light sources is scarcely more than in its infancy and so far has been confined largely to lamps whose gas pressure does not exceed one atmosphere. While it would appear unlikely that an arc discharge in either of the gases neon or argon will result in a light source of practical interest, it is almost certain that new xenon lamps will be developed. If, as lamp-making techniques improve, it is found possible to overcome the difficulties associated with high gas pressures the gas arc discharge lamp should find many new applications.

The author wishes to express his indebtedness to Dr. J. N. Aldington for help and advice in the preparation of this paper and for permission to publish the results of experimental work done under his direction.

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Discussion

MR. H. R. RUFF: It is with great pleasure that I have been able to accept the invitation to open this discussion on Mr. Cumming's survey of the subject of high-pressure gas discharges. While many of the points raised in the earlier paper by Dr. Aldington still remain to be solved, I am particularly pleased to note that in spite of the apparent gains due to water-cooling, most of the advances since the earlier paper have been concerned with air-cooled lamps. We are, apparently, still faced with the problem of the difficulties of installing water-cooling from the user's point of view. It is also interesting to note that the life of the 5-kw water-cooled lamp appears to have settled down at a value similar to that of the corresponding water-cooled mercury vapour lamp, although earlier we had rather expected that it might be more.

May I pay a tribute to the painstaking laboratory work of which this paper is an example? It is now three years since the 5-kw lamp was introduced and Mr. Cumming has expressed the view that these sources are little more than in their infancy. Much work of this type, in a number of laboratories, is necessary before any new practical sources appear: much of it must contribute to the store of our knowledge rather than give direct practical results. While some simplification has taken place, both in the elimination of the water-cooling of the lamp and in methods of operation, the practical sources still remain somewhat complex and expensive, and the present applications of the lamps cover largely special work where they can do something which other sources

can do only with great difficulty. Whilst the use of xenon contributes considerably to the cost, efficiency and colour considerations make its use necessary for most practical gas discharge lamps.

In our experience the main uses of the linear sources of the 1,000-watt type have been for laboratory tools. For such laboratory work the near infra-red is sometimes of considerable interest, and there are five very strong lines in the spectrum of the xenon lamp in the region of 7,500 Å to 10,000 Å. The author mentions the use of the 1-kw lamp for fading tests and I would be interested to know if it has been found necessary to remove this radiant heat in order to preserve the necessary humidity conditions for the samples.

The use of gas discharge sources for artificial plant growth is interesting and they may have some application where high light intensities are necessary. The fluorescent lamp is now very widely used for this work, and intensities up to about 1,500 lumens per sq. ft. have been achieved. In addition to the designed control of the radiation possible with the fluorescent lamp, its characteristic long life and, in particular, its high efficiency and low radiant heat characteristics, have proved most valuable. Plants have been grown throughout the year enabling, for instance, fertiliser experiments to be carried out continuously together with the many allied scientific investigations that such growth permits. A gas arc source might prove a useful addition to the fluorescent lamp background to provide the higher intensities associated with direct sunlight, but with these intensities and the infra-red radiation from the gas arc, cooling problems would be greatly increased.

While no compact source gas arc has yet been standardised, the most likely application for quantities of these lamps is still, in my opinion, in that form. In such a form the lamp can have not only the colour quality we normally associate with it, but it will give a brightness considerably greater than that of incandescent lamps. In the achievement of these higher brightnesses, high gas pressures are most helpful. There is no practical difficulty in filling such lamps to any pressure but we have limited lamps made in our laboratories to two atmospheres pressure with the lamp cold. This is to avoid dangers from explosion when handling. While still higher pressures would be helpful, the pressures so far achieved can give useful light sources provided the cost and complexity can be reduced and the practical lives are of the order of 500 hours.

Lamp designers are continuing their efforts on these problems but, to stimulate discussion, may I respectfully suggest that only rarely do suggestions for new light sources come from lighting engineers. Nevertheless, many of their achievements have been stimulated by the introduction of new lamps, the effect of electric discharge lamps on street lighting and fluorescent lamps on large area lighting being conspicuous examples. Any comments that lighting engineers can give concerning, for instance, water-cooling versus air-cooling, linear versus compact sources and the colour of the lamps, following Mr. Cumming's most able description and demonstration will, I know, be much appreciated.

MR. A. G. PENNY: There was a time when research and commercial people took a very meagre interest in each other's activities, but a change in attitude has taken place in recent years, although I think that the pendulum has swung rather too far the other way. We may, however, be grateful that Mr. Cumming has been allowed to work in the very interesting, but as yet, not very profitable field of xenon discharges.

I am glad Mr. Cumming recognises the inaccuracy of the description "Gas Arc," although he continues to use it. Mr. Cumming pays tribute to other workers in this field, but he omits reference to the work of Schultz, who published data in 1939 on discharges in rare gases at high pressures and fairly high current densities.

I should like more information regarding the electrical stability of the compact

source xenon arc. I understand Mr. Cumming to say that a 10 per cent. change in mains volts changes the wattage by 30 per cent., which is something like twice the change that occurs with tungsten or mercury lamps. Is this correct? The overall efficiency of the D.C. xenon-type lamp is clearly very poor, but can Mr. Cumming give details of the sort of power factor correction needed to obtain a power factor of 0.85 on A.C.? There is also the question of the overall weight of the gear. I am interested to note that Mr. Cumming now appears to favour high-frequency starting. We have always felt that that method, although more complicated than that originally suggested, is likely to be more practical.

With regard to the optical control of these lamps, I understand that the stability of the arc depends very largely on the shape and surface condition of the electrodes, and I should be glad to know what precautions Mr. Cumming advises. This is a factor which has wider importance than is generally realised, because an unstable discharge which is obviously unsuitable for projection is, nevertheless, also quite unsuited for general purposes. Anyone who has to work under a light source which is apt to flicker knows how unpleasant it is. It is interesting to hear that the brightness of the compact source lamp is only two to three times that of tungsten projector lamps, unless very high pressures are used. These lamps would not appear to have a great future in the film projection field, in competition with the simple and cheap filament lamps. At the same time the possibility of the projection of coloured films with an important degree of colour rendering is not to be ignored, although higher powers are wanted than have been demonstrated in the projectors to us to-night. I feel, however, that even the 1-kw. lamp has a very serious competitor in the well-established 1-kw. carbon arc which is coming into considerable use for 16-mm. projectors.

Mr. Cumming referred to the use of the lamp as an accurate source of colour matching, and I would like to have his comments on it compared with other sources of artificial light for really critical colour matching.

The demonstration of the infra-red radiation from the lamp is very interesting, but I understand that the mercury-compact source lamp has about 50 per cent. more infra-red radiation per watt in the 7,000 Å to 12,000 Å region than the xenon lamp. It may be a lot easier to use the xenon lamp if you have to filter out the visible light, because of the smaller amount of visible light from the xenon lamp. For some purposes this will be important.

It seems to me that the urgent requirement for the xenon lamp is that of finding a strong, transparent bulb to withstand very high pressures. This would greatly widen the field of use of this lamp by making it possible to have very much higher brightnesses. In the meantime, the explorations of Mr. Cumming have provided all workers with a great deal of useful data, and I congratulate him on his lecture and especially on the demonstrations.

MR. E. J. G. BEESON: I have been mainly concerned with the development of compact source xenon lamps as distinct from the linear or water-cooled types. The experience and techniques used in the design of the more familiar linear and compact source mercury lamps have been most useful, but as yet the xenon discharges are no direct competitors of the higher brightness, higher efficiency, mercury lamps—although we are aware that both gas and mercury discharges have their advantages and limitations. In the design of xenon lamps for D.C. operation, the limiting factor in use is the characteristic high current density required with the correspondingly low arc voltage. Providing the user is prepared to accept the low overall efficiency when operating a lamp from a normal D.C. supply, or is able to provide the necessary low voltage supply,

it is quite practical to make lamps of 1, 2½ and 5 kw. with lives comparable with the mercury type lamps with source brightnesses of 8,000, 15,000 and 40,000 stilb.

For A.C. operation there is no problem in providing a low voltage supply, but due to high arc current the electrodes become a problem in themselves. For example the life of a 5-kw or 10-kw A.C. compact source mercury vapour lamp is not much greater than 100 hours and a 1-kw xenon lamp in a compacted form will be taking the same current as a 5-kw mercury lamp. Therefore until such electrode problems are resolved so that lamp life is increased, the compact source xenon lamp is likely to be rather costly. I should like to have the author's views on the results he may have obtained with A.C. compact source xenon lamps and to ask if there are reasons other than arc stability to explain why most of his very detailed results have been obtained with D.C. operated lamps.

The application of experimental compact source xenon lamps to 16-mm. colour-film projection has already shown very promising results and has been used very successfully, first at the British Electrical Power Convention at Harrogate in June, 1950, and recently in the Faraday Lecture. The light output is appreciably greater than with a tungsten lamp of equal power and the colour rendering is very pleasing, but it is necessary at this stage to be a little cautious as most 16-mm. colour-films are processed for projection with either tungsten or carbon arc lamps. The radiation or colour temperature of the xenon source falls in between these two.

I feel that the xenon lamp will undoubtedly have its main use as a compact source type, as in most applications one does require a high brightness source for efficient utilisation.

MR. E. H. NELSON: There are three points concerning the construction and use of high pressure xenon discharge lamps which I should like to raise.

The first concerns the use of increased gas pressure, which I agree is of great importance. We have done a little work on the storage of gas in absorbent materials contained in the lamp bulb, but the results are not so far very promising. Has Mr. Cumming any views on the practicability of this method of storing large volumes of gas at relatively low pressure?

The second point is one which Mr. Penny has already mentioned. We have found that the shape and surface finish of the electrodes plays an important part in determining the stability of the arc. It is interesting to note that the best contour for the electrodes seems to depend, among other things, on the frequency of the electrical supply and the burning position of the lamp. The point is of considerable technical interest since a study of it may lead to a better understanding of the causes of arc instability.

The demonstration of a signalling lamp was particularly interesting. The rapid response of discharges to changes in current is a most useful feature, but it did not appear to me that the ratio of "dark" to "light" illumination in the lamp demonstrated was sufficiently high for clear signalling. I should like to have Mr. Cumming's views on this.

MR. J. G. HOLMES: If an illuminating engineer may suggest the specification of a lamp which would prove useful for general application, I would ask for a bar-shaped light source, about 10 in. long by 1 in. diameter, consuming about 300 watts, giving white light at an efficiency of over 30 lumens per watt and having simple auxiliaries (or none), and I wonder whether we can look to the gas arc for developments in this direction. Such a lamp would be of the greatest value in street lighting and in many industrial applications, especially if it had a long life and could be burnt in any position without complicated auxiliaries.

Can Mr. Cumming differentiate between the gas-discharge and the gas-arc states

by reference to the mechanism of the passage of the electric current and the mechanism of the emission of the light?

MR. G. WIKKENHAUSER (communicated): I very much regret that I was not able personally to attend the meeting to listen to Mr. Cumming's lecture on this high-intensity gas-arc lamp. I had opportunity to acquaint myself personally with high-pressure xenon gas-arc lamps made by the author, mainly in connection with the illumination side of an instrument which I will call, in the absence of any better term, a Photographic Radar Projector, which gives a large screen-projected image of a Radar P.P.I. picture with a time delay of a few seconds. In this connection we found the xenon arc lamp much superior to any other compact light source, particularly because of quick starting and restarting, instantaneous full light output and the very near approach to "white light." The necessary starting and driving gear for the lamps, perhaps, is not developed to such perfection as the lamps themselves, and the necessary high current leads to heavy electrical gear. However, I am confident that, with further development, this difficulty will be satisfactorily overcome.

In view of Mr. Cumming's remarks in connection with the 1-kw. lamp, which he says has a modulable light source, I would like to ask whether he considers it feasible that such a lamp can be used, if necessary in a modified form, as a high-intensity stroboscopic flashing light source flashing at the rate of 50 times per second or thereabouts, with a flash duration of something like 50 microseconds. Having made experimental film projectors with continuously moving film with a stroboscopic light source, and having seen the possibilities of such a projector, I would like very much to try a lamp in such a set-up. Because of the geometrical shape and size of the discharge and the high light output, I feel it would make such a project practically feasible. Could Mr. Cumming say something about this aspect of these lamps?

DR. J. W. STRANGE: The author stated that the arc can operate without any form of ballast. That is a most interesting point which I wish he would discuss in greater detail.

MR. H. W. CUMMING (replying to the discussion): In reply to the interesting points raised by Mr. Ruff, it is recognised that water cooling can be a disadvantage, particularly where it is essential to move the light source. On the other hand, the water-cooled lamp results in a relatively cool light as unwanted heat is removed by the water. Up to the present, the practical applications for xenon lamps are specialised but it is not altogether true that other lamps can be used as alternatives even if with great difficulty; sometimes there are no alternatives.

The 1,000-watt XB/U lamp is not necessarily limited to laboratory use. If, for example, it is found possible to produce a simple means of initiating the arc it is likely that this light source will be widely used.

Regarding infra-red applications for xenon lamps, measurements taken with a small water cooled linear source lamp indicate that xenon gives powerful radiation peaks at 8,200, 8,800 and 9,100 $\mathring{A}$ with somewhat smaller peaks at 7,600, 9,400 and 9,850 $\mathring{A}$ The Krypton lamp with main radiation peaks at 7,500, 8,050 and 8,125 $\mathring{A}$ and a minor peak at 8,850 $\mathring{A}$ may be preferable for some uses. In reply to Mr. Penny's question concerning the infra-red characteristics of gas-arc lamps, the ratio of the infra-red output from xenon to that from mercury per unit watt dissipated can be unimportant. Major factors which determine this include: (1) The wave lengths at which the infra-red radiation occurs; (2) The importance of immediate utilisation when the lamp is switched on; (3) The amount of simultaneously produced visible energy, and (4) The complexity of the equipment. Where the 1-kw. XB/U lamp

has been used for fading tests, the temperature rise on the samples under test has been reduced by adjusting the distance between the light source and the samples.

Mr. Ruff's remarks on the use of gas discharge sources for artificial plant growth are most welcome. K. J. Mitchell has reported that where high illumination is required the gas arc is likely to be the only suitable source. The continuous radiation from the xenon arc is an advantage compared with the radiation from tubular fluorescent lamps, with its peaks at wavelengths associated with the low pressure mercury spectrum.

The electrical stability of the xenon arc is better than that of the mercury lamp as changes in the mains voltage will only produce minor changes in the arc current.

Overall efficiency of the D.C. compact source xenon arc has been stated to be poor and unless suitable low voltage generators are available for an application there appears to be no solution to this problem. It was interesting to have the confirmation of Mr. Beeson on this point. For A.C. operation step-down transformers can be used and in certain cases power factor correction can be applied by means of electrical capacitors. For example, considering a hypothetical source operating from a 220-volt 50-cycle single phase A.C. supply at 25 volts with an arc current of 22.5 amperes, it would be necessary to use a capacitor of the order of 300 microfarads in order to correct the power factor to 0.85.

The equivalent colour temperature of the several forms of gas arc vary from about 5,500 deg. K. to 6,000 deg. K. depending upon the concentration of the arc and upon the current density.

The information given in the earlier sections of the paper was obtained from sources operating on direct current because, as Mr. Beeson supposes, the arc stability is better with this method of operation, but in the later sections, particularly those of 2.5 and 2.6, all the data given were obtained from lamps working on alternating current. With mercury lamps better maintenance can be obtained on alternating current than on direct current and therefore it is to be expected that the same results will be achieved when using the compact source xenon arc.

I am indebted to Mr. Wikkenhauser for his communication describing a typical application for a low-wattage xenon arc lamp. As regards stroboscopic operation of such lamps, it should be remembered that the small, compact source xenon lamp has a low-arc voltage and will operate from 50 cycles A.C. on a line voltage as low as 70 volts. Consequently, to flash this lamp with a flash duration of something like 50 microseconds, a condenser discharge method would have to be considered. This would not be a practical proposition unless the current flow was controlled at each flash by operation in series with some form of thyratron. Under these conditions some energy will be dissipated in the thyratron-plus lamp, and, in order to obtain high overall efficiencies, it would be necessary to ensure that at least 50 per cent. of the energy was used in the lamp.

In attempting to reduce high gas pressures when the lamp is not in operation, activated charcoal has been tried with a view to absorbing the excess gas pressure. It would be interesting to know what methods Mr. Nelson has used. The disadvantage of using charcoal is that large volumes of gas cannot be absorbed unless the charcoal is cooled each time to low temperatures.

The signalling lamp that was demonstrated gives a rapid response to changes in arc current and was designed to take some 5 amperes in the "dark" period with 100 amperes through the main arc in the "marker" period. Due to current limitations it was only possible to operate it under considerably reduced loadings during the lecture, and this resulted in what Mr. Nelson observed as an insufficient ratio of dark to light illumination. Actually, ratios as high as 100 : 1 can be readily obtained.

It was useful to have from an illuminating engineer the specification for a light source for general application. While it would be possible to use a tubular xenon arc

not unlike the XB/U lamp to give an arc some 10 ins. long, it is unlikely that the diameter would be as great as 1 in., particularly under loadings of the order of 300 watts, while at the same time giving white light at an efficiency of over 30 lm./w.; a width of perhaps ¼ in. might be achieved. This could perhaps receive some correction by coating the quartz envelope with a thin film of silicon dioxide to obtain high diffusion without seriously reducing the luminous flux. For operation from normal A.C. mains some form of choke would be necessary and, in addition, a simple means of initiating the arc. Mr. Holmes's specification will be valuable in serving as a goal for the research and development engineer.

There can be no hard and fast distinction between a discharge and an arc. In general, arc sources emit radiation as a result of the maintenance of a comparatively low voltage ionic electrical discharge under conditions in which the material of the electrodes may be present in the arc stream and may provide a large proportion of the conducting and radiating ions. Discharge tube sources emit radiation by maintaining an ionic discharge in a gas at low pressure, the gaseous atoms providing the necessary ions. With the announcement of the 5,000 watt XA/U lamp where very heavy currents were passed through a gas at high pressure, it was felt that some distinction in definition should be made, and in view of the resemblance of the form of discharge to what had previously been termed either purely an arc or purely a gas discharge, the expression Gas Arc Discharge was used.

In the written paper an example is given of the operation of an XA/U lamp with an arc voltage of 65 on a D.C. voltage of 65 volts without any ballast resistance. To investigate this characteristic the 5 kw XA/U lamp is operated in series with an adjustable resistance from a D.C. generator giving a normal line voltage of 110 volts. If this generator is equipped with a field regulator, the line voltage can be reduced while the current can be held at the normal operating value by adjusting the resistance. Ultimately it will be found that the voltage supplied by the generator will be the same as the operating voltage of the lamp and at the same time it will be found that the whole of the ballast resistance will have been eliminated.

Additions to the List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members.

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